

ANALYSIS OF WINDSCREEN DEGRADATION ON ACOUSTIC DATA

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ABSTRACT

Windscreens have long been used to filter undesired wind noise from acoustic data. However, little research has been conducted to study the effects on acoustic data when windscreens are exposed to harsh environmental conditions. The physical property of a foam windscreen is inevitably degraded when exposed to prolonged periods of UV rays and dust such as that in Iraq and Afghanistan. This degradation, if not accounted for, can result in significant accuracy errors of mission sensitive technology used to process acoustic data for purposes such as localization and tracking of targets of interest. The following research compares, in a controlled anechoic environment, the frequency and phase response of a clean windscreen to that of several windscreens with varying amounts of dust and sun exposure.

1. INTRODUCTION

Windscreens are used to filter undesired wind noise from acoustic data. Many of these windscreens are used for years with no maintenance and very little consideration placed on its wear-and-tear. Recently ARL has been receiving feedback suggesting that their acoustic systems localize targets more accurately when windscreens were eliminated. The initial thought was that this was impossible, however after receiving a windscreen returned from the desert it was noticed that its physical appearance and possibly its physical properties had changed. In a continuing effort to improve upon localization accuracy of the Army Research Laboratory's mortar/sniper detection systems, the following windscreen analysis was conducted.

2. EQUIPMENT

Three 6" foam windscreens were examined during this experiment. The first one was new (and from now on, labeled as "clean"), the second one had been exposed to mid-Atlantic sun and some suburban dust particles ("exposed"), and the third one was heavily infiltrated with sand as a result of lengthy usage in the desert ("dusty"). The exposed windscreen was left untouched throughout the test so its average exposure to sunlight was more severe on its south facing side. We will therefore consider the exposed windscreen as two

windscreens, a south facing one ("south exposed") and a north facing one ("north exposed"). Since the dusty windscreen was being regularly dusted out in the field, its exposure to sunlight can be considered to be more uniform all around, so we will not make that differentiation.

Testing was conducted in a semi-anechoic chamber with a cutoff frequency of 150 Hz. The data acquisition equipment consisted of two B&K microphones (Type 4166), a B&K preamp set to 0dB, and a 24-bit National Instruments data acquisition board. A Bazooka BT1024DVC speaker along with an amplifier set to -9dB and a WAV file was used to generate a chirp between 40 and 500 Hz. This frequency range was chosen because it covers many military targets of interest, from mortar, artillery, rockets, to wheeled and tracked vehicles. Data was collected for each sweep at a sampling rate of 5 kHz. The speaker has a flat frequency response between 39-1500 Hz.

3. EXPERIMENTAL SETUP AND PROCEDURE

The three windscreens were weighed to characterize the effect of extra material in the foam. Table 1 below contains the weight of each windscreen prior to testing. The accuracy is $\pm 1\text{mg}$.

	Clean	Exposed	Dusty
Weight (g)	55.880	56.232	75.702

Table 1

During this entire experiment, two microphones were placed 0.222m apart, and elevated 0.99m. They were located 1.55m away from the speaker, which was elevated 1.09m from the ground. One microphone was always bare and acted as the reference microphone. The other carried the various windscreens.

Due to the frequency response of the speaker, all data was analyzed between 50 and 450 Hz. Figure 1 illustrates the spectrogram of the input signal out of the sound card, prior to going through the amplifier and speaker.

Report Documentation Page			Form Approved OMB No. 0704-0188		
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1. REPORT DATE 01 NOV 2006		2. REPORT TYPE N/A		3. DATES COVERED -	
4. TITLE AND SUBTITLE Analysis Of Windscreen Degradation On Acoustic Data				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) US Army Research Laboratory Adelphi, MD 20783				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release, distribution unlimited					
13. SUPPLEMENTARY NOTES See also ADM002075., The original document contains color images.					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UU	18. NUMBER OF PAGES 5	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

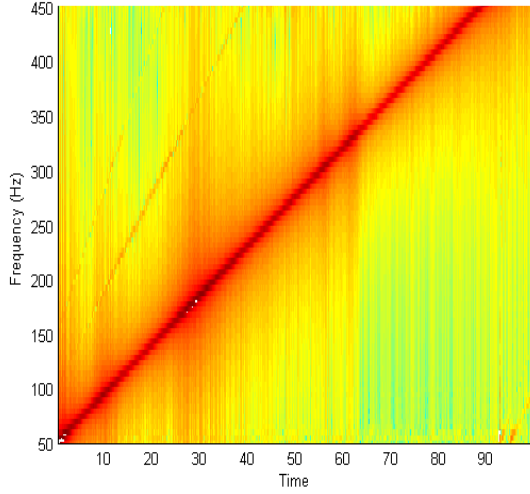


Figure 1

The waveform played by the sound card was compensated for the unknown transfer function of the amplifier and speaker system. It was chosen so that the signal measured at the bare microphone would be as close as possible to an ideal chirp between 40 and 500 Hz. We did not attempt to compensate for the nonlinearities in the system (indicated by the harmonics in Figure 2), as they are not significant. The amplifier/speaker transfer function was estimated prior to the experiment itself. It was accomplished by measuring the signal at the output of the sound card and at the bare microphone.

3. TRANSFER FUNCTION

The transfer function of each windscreen was derived as followed. Let microphone 1 be the reference microphone, and microphone 2 be the microphone with clean windscreen, exposed windscreen, dusty windscreen, and no windscreen. Then, the transfer function of each windscreen is, respectively,

$$T_{2c} = \frac{X_{2c}}{X_{1c}} \frac{X_{10}}{X_{20}}, \quad T_{2e} = \frac{X_{2e}}{X_{1e}} \frac{X_{10}}{X_{20}}$$

$$T_{2d} = \frac{X_{2d}}{X_{1d}} \frac{X_{10}}{X_{20}}, \quad T_{20} = \frac{X_{20}}{X_{10}}, \quad (1)$$

where X_2 is the Fourier transform of the measured signal at microphone 2. The second index c indicates the clean windscreen, e the exposed windscreen, d the dusty windscreen, or 0 no windscreen. The frequency variable ω has been dropped for convenience. T_{2x} can be understood as the effective transfer function from microphone 1 to microphone 2, when a windscreen is added into the path.

Another way to interpret (1) is to observe that the sweep signal, though nominally identical from experiment to experiment, is not synchronized with the data acquisition system, so X_{2c} and X_{20} do not have the same time origin. Therefore, their ratio X_{2x}/X_{20} will have an unknown delay phase in it. However, the reference microphone will have the same unknown phase delay too. Therefore, this phase delay can be cancelled out by multiplying X_{2x}/X_{20} by X_{10}/X_{1x} , which has unit norm. This leaves T_{2x} as the desired ratio X_{2x}/X_{20} , but properly synchronized.

4. RESULTS

Figure 2 illustrates the spectrogram for the signal measured at the clean, south exposed, north exposed, and dusty windscreen respectively. One might notice some signal loss as the degradation of the windscreen is increased.

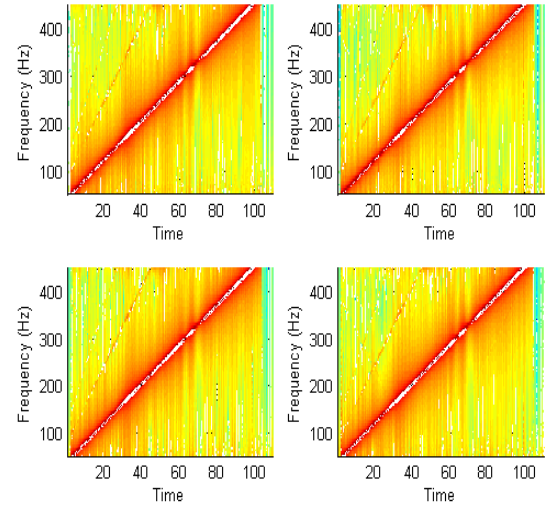


Figure 2

The magnitude of T_{2c} , T_{2se} , T_{2ne} , and T_{2d} are found to be within a factor of 0.1 dB of each other (Figure 3). There seems to be a mild high pass effect. This could just be the low frequency tail of the roll-off of the natural resonance frequency of the windscreen, which would peak around $f_r = c/(2D) \approx 1 \text{ kHz}$, where D is the diameter of the windscreen and c is the speed of sound.

One might notice valleys around 100 and 150Hz. These correspond to some resonance frequencies of the 20x20ft chamber, which is not rated anechoic below 150Hz. The microphones might be near a dead zone of

the standing waves. A standing wave is a vibrational pattern created within a medium when the vibrational frequency of the source causes reflected waves from one end of the medium to interfere with incident waves from the source in such a manner that specific points along the medium appear to be standing still.

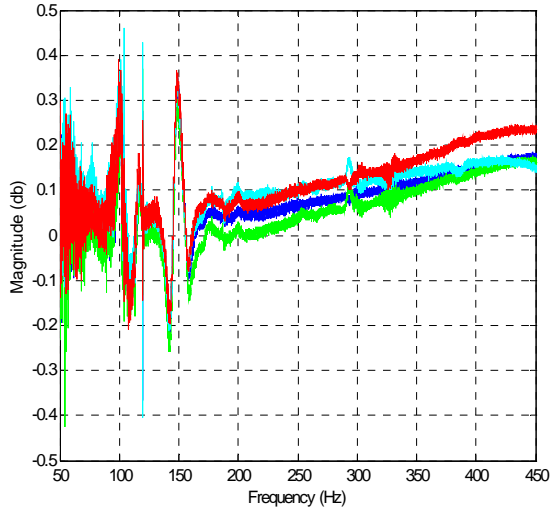


Figure 3

Figure 4 shows the phase response of each windscreen. These are given by the argument of the transfer function T_{2x} . Blue, green, cyan and red curves correspond to the clean, south exposed, north exposed, and dusty windscreen respectively.

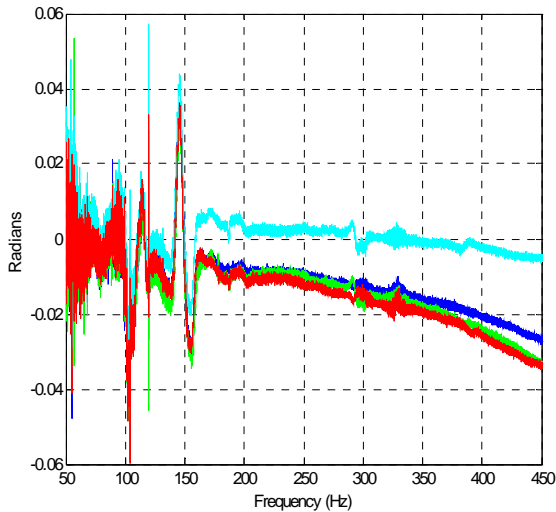


Figure 4

There is a small phase lag between the different windscreens. The above graph shows that the dusty windscreen has the greatest amount of delay, followed by the south exposed windscreen, then by the clean windscreen. The only odd result is for the north exposed windscreen, which barely exhibits any delay. In fact, it even takes unphysical values (positive phase).

Our interpretation is that the dust affects the porosity and density of the windscreen material, increasing its acoustic capacitance as a transmission medium. The odd effect of the north exposed windscreen may be due to an increase in the hardness of the medium, which increases the speed of sound propagating through it. This effect is not observed on the sun exposed side possibly because the UV makes the material more brittle.

Figure 5 shows the corresponding time delay as function of frequency. One can see that the delay very slightly increases above 150 Hz, averaging mostly around 10μs.

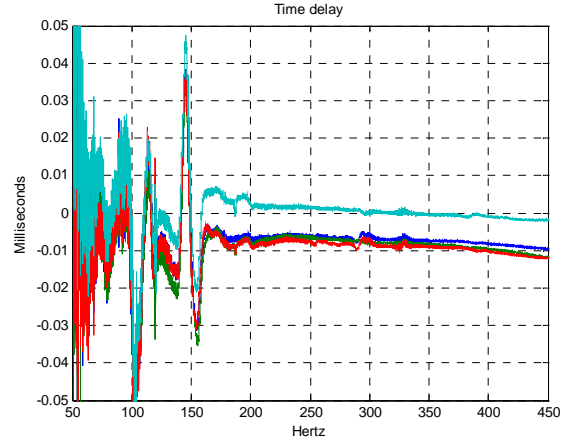


Figure 5

One will also notice peaks around 100 and 150 Hz. This feature is present in both the phase and magnitude curves, and might be explained by the standing waves at frequencies below the cutoff frequency of the anechoic chamber. Not being a traveling wave, the phase delays cannot be interpreted as propagation delay through the windscreen anymore.

The phase behavior of the various windscreens do not change with signal strength. This is shown below in Figure 6, 7, and 8, where the amplitude of the input signal amplitude was varied from $\sqrt{\frac{1}{2}}$, $\sqrt{2}$, to $\sqrt{3}$ times

its initial value. Our laboratory equipment prevented measuring at higher signal power. However, we can reasonably predict that, for the kind of signal we expect to be dealing with, the windscreen degradation acts a linear filter on the signals.

To be perfectly rigorous, a linear system must satisfy the superposition property too. Unfortunately, as we have noted, the exposure to the sun is not spatially uniform, so multiple signals from different direction can not be expected to undergo the same filtering effect. However, a phase difference of $10\mu\text{s}$ can be negligible, depending on how far the microphones of an array are spaced apart.

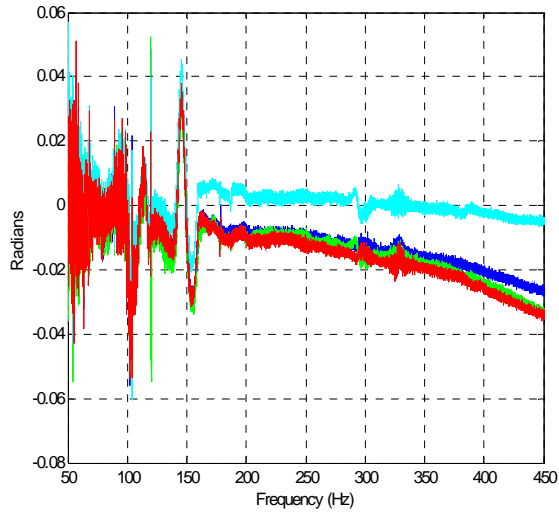


Figure 6

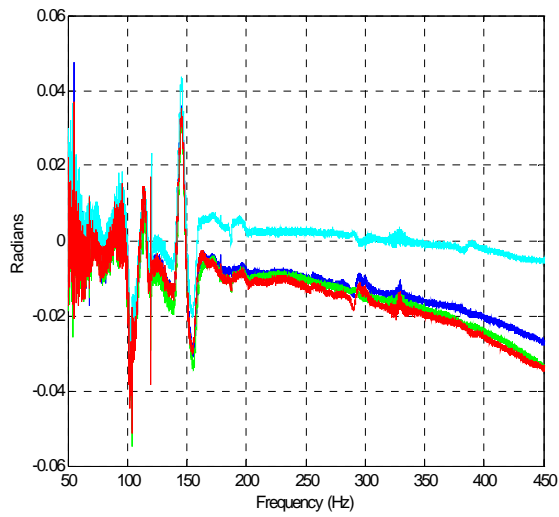


Figure 7

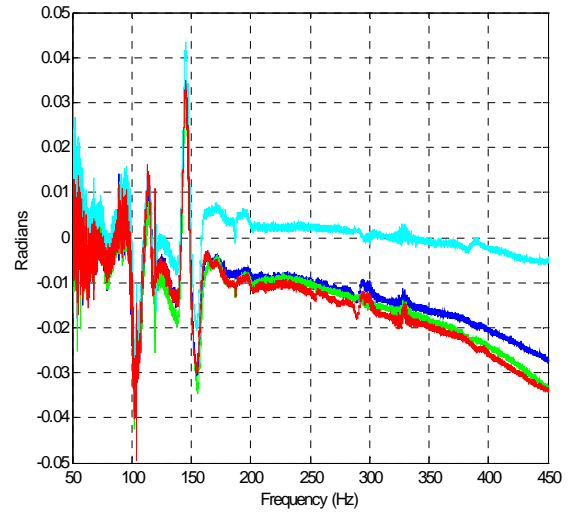


Figure 8

To reinforce the idea, Figure 9, 10, 11, and 12 summarizes the effect of varying signal power when the windscreen is kept fixed (clean, south exposed, north exposed, and dusty resp.) as amplitude increases through the 4 multipliers.

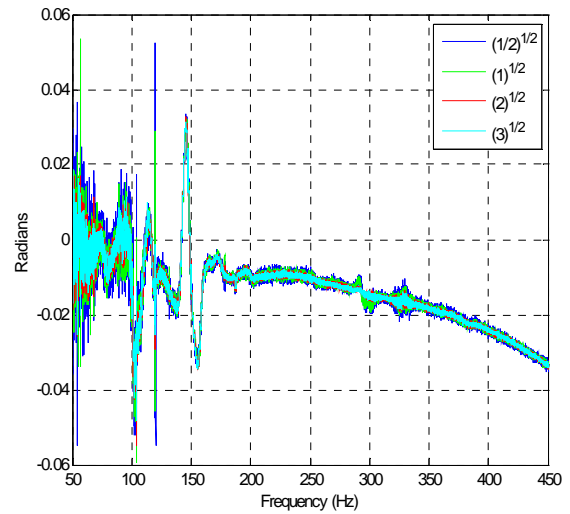


Figure 9

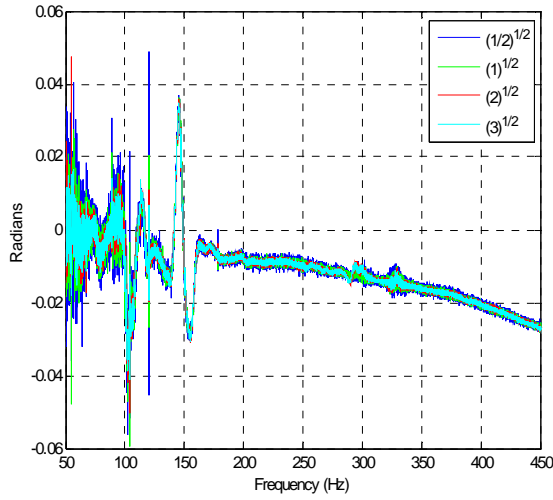


Figure 10

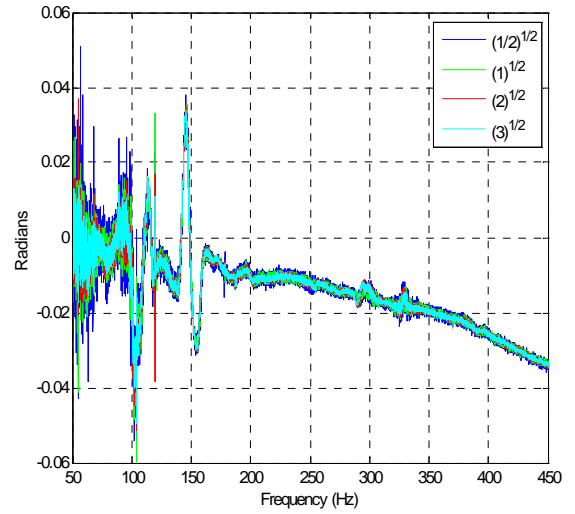


Figure 12

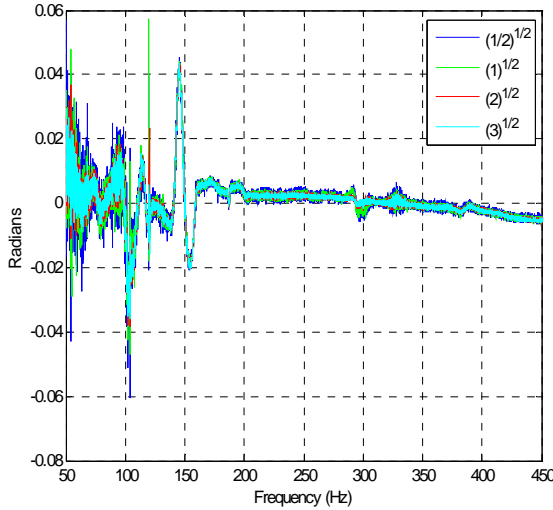


Figure 11

5. CONCLUSION

Windscreens play a critical role in filtering wind noise from acoustic data. However, windscreens used for a prolonged period of time are eventually degraded by environmental conditions. This degradation has little effect on amplitude and phase. However, it is there, and seems to depend on the direction of average sun exposure, material hardening, and amount of dust in the windscreen. This dependency has not been modeled at this point, and more extensive measurements are needed to confirm our findings.

One positive note is that the extra delay is the order of tens of microseconds. For a typical acoustic array of 1m radius, the induced timing error on detected events produces barely an angular error of $\pm 0.5^\circ$ on the estimated direction-of-arrival. Of course, we have just examined a particular windscreen from the field. Some of them could have been out in the desert for years, and the degradation could be much more significant. This is an issue that should be seriously studied.

Future work includes a more quantitative model of the windscreen material and the effect of dust amount and exposure to sunlight.

6. ACKNOWLEDGEMENTS

The authors would like to thank Mr. Mike Scanlon and Mr. Gene Whipps for their help and suggestions during the duration of this research.